A Method for Comparing Annual and Seasonal Cycles of TOA Fluxes: a Test Case Using CERES EBAF and the GSFC GEOS-5

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Seasonal Cycles of Absorbed Solar Radiation (ASR) and Outgoing Longwave Radiation (OLR) provide a strong Validation Test

- This is a method to compare objectively the observed TOA seasonal cycle of ASR and OLR with models.
- The hope is to facilitate analysis not apparent in the JJA and DJF comparisons.
- We consider the time variation rather than a series of snapshots of monthly or seasonal means.

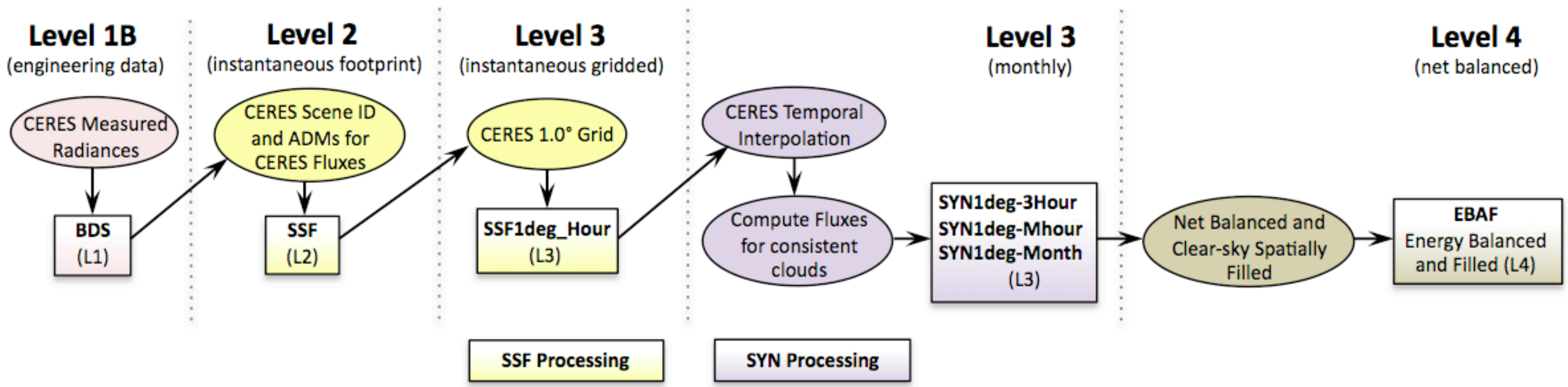
Outline

- GEOS-5 CERES comparison
- Annual mean
- Seasonal cycle
- Approach using principal component analysis
- How to characterize seasonal cycle bias?
- What can we learn from this?

Data

- CERES EBAF Ed2.6 monthly means of ASR and OLR for
  - 1°x1° regions
  - March 2000 through August 2007, the period of overlap with GEOS-5
- GSFC GEOS-5 AGCM
  - Fortuna 2_2
  - monthly means for same time period as CERES
  - 1° resolution
  - AMIP style run

CERES EBAF



EBAF Edition 2.6 is available at:
http://ceres-tool.larc.nasa.gov/ord-tool/jsp/EBAFSelection.jsp
Global annual mean values are adjusted so that the 2006-2010 mean net TOA is 0.58 ± 0.38 W m^{-2}.

Approach

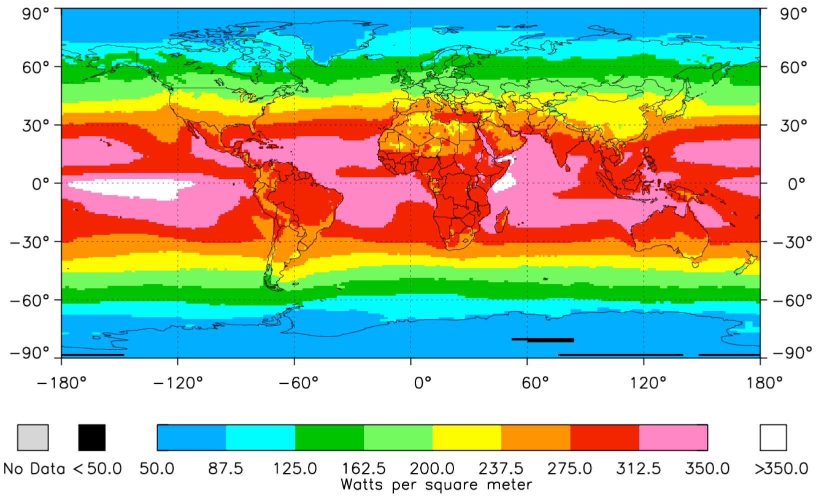
- Express ASR and OLR as

  $F(x,t) = F(x) \quad + \quad Y(x,t)$

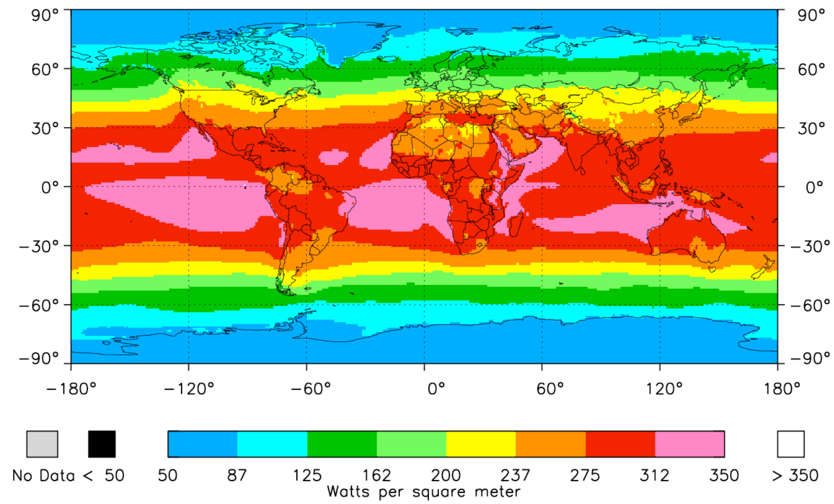
  Climatological mean (average Jan. etc.) = Annual Mean + Seasonal Cycle

- First examine Annual Mean, then the Seasonal Cycle.

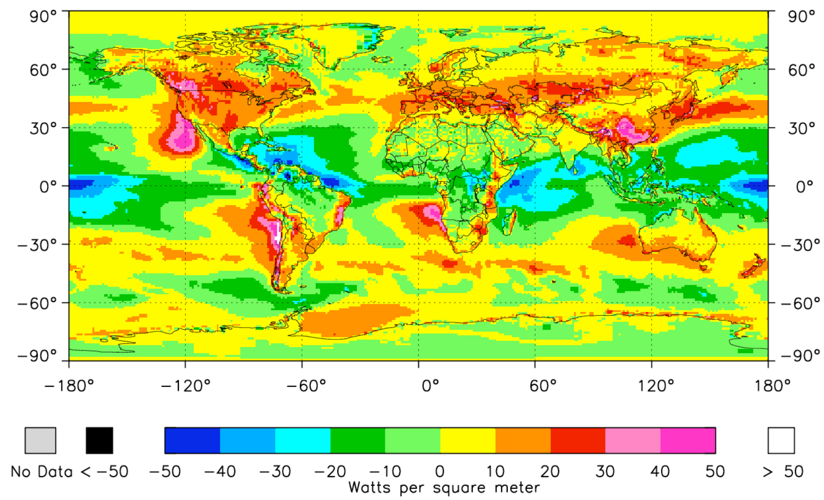
Annual Mean ASR



EBAF

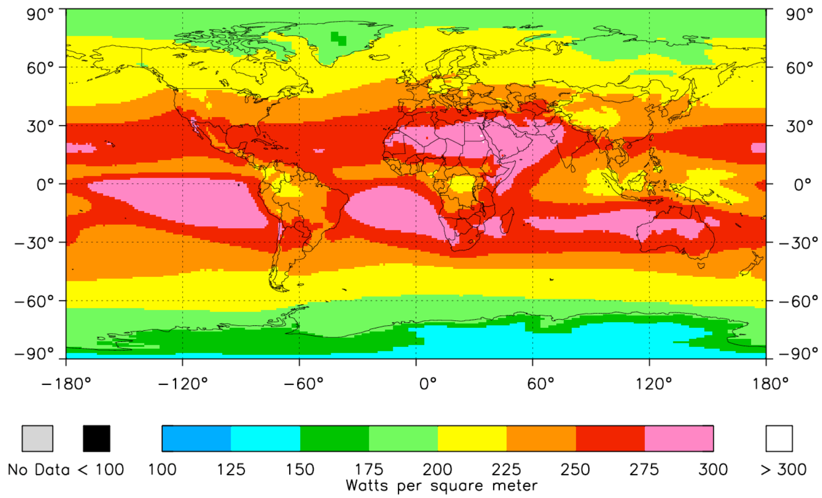


GEOS-5

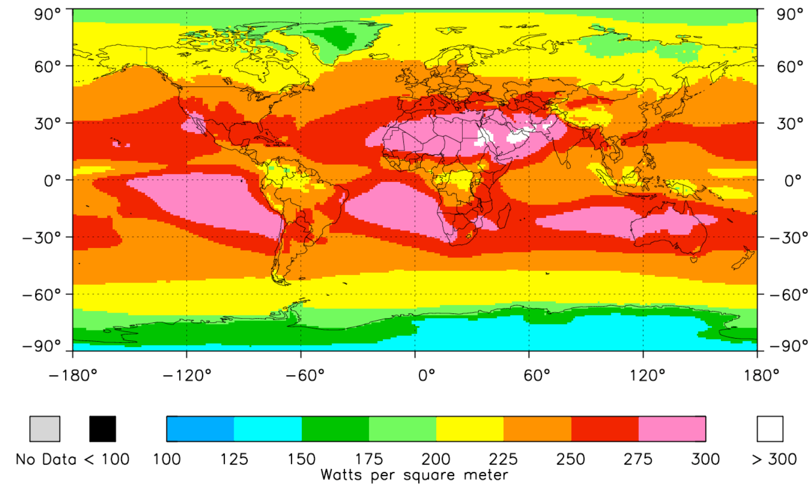


Difference: GEOS-5 - EBAF

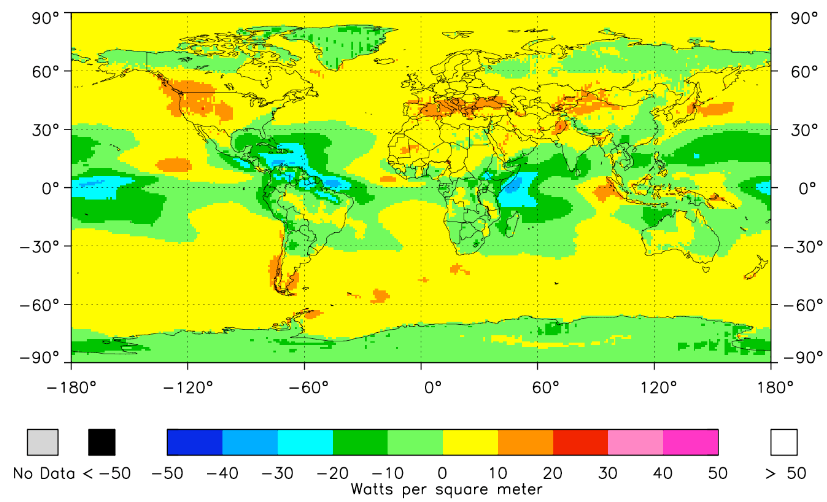
Annual Mean OLR



EBAF



GEOS-5



Difference: GEOS-5 - EBAF

From the previous maps: Global Averages of Annual Mean Fluxes, W m^{-2}

	EBAF	GEOS-5	GEOS-5 – EBAF	RMS of difference
ASR	240.26	241.45	1.18	13.7
OLR	239.82	242.95	3.13	8.1

RMS of Seasonal Cycles, W m^{-2}

RMS	ASR/EBAF	ASR/GEOS-5	OLR/EBAF	OLR/GEOS-5
Land	**72.1**	**76.9**	**21.4**	**23.6**
Ocean	**73.3**	**74.1**	**12.1**	**13.7**

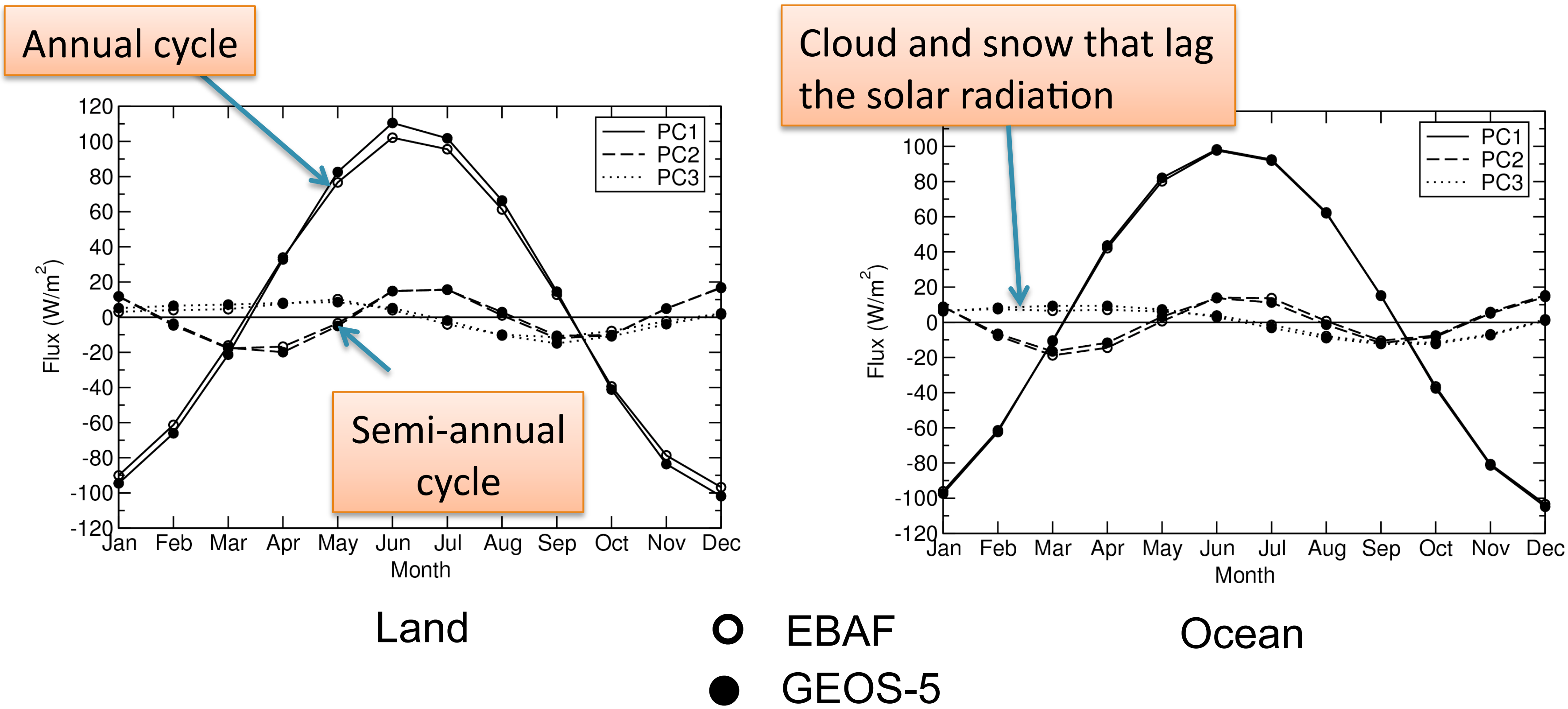
The RMS of ASR and OLR with annual mean subtracted i.e. the RMS of the seasonal cycle.

Principal Component Analysis

- EBAF: $Y(x,t) = \Sigma_n PC_n(t)\ EOF_n(x)$
- GEOS-5: $y(x,t) = \Sigma_n pc_n(t)\ eof_n(x)$

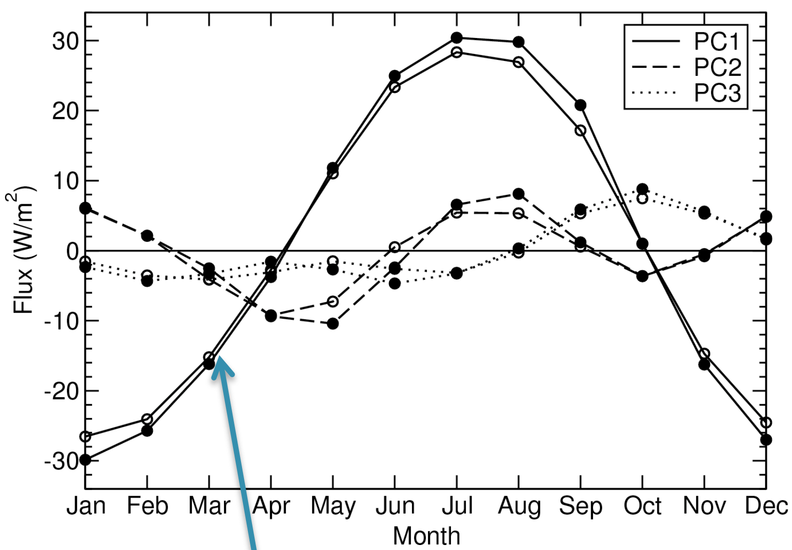
- Y and y are the seasonal cycles from EBAF and GEOS-5, respectively.
- The principal components (PCs) describe the time variation of the seasonal cycle.
- The empirical orthogonal functions (EOFs) correspond to the PCs and describe the spatial variations.

ASR Principal Components

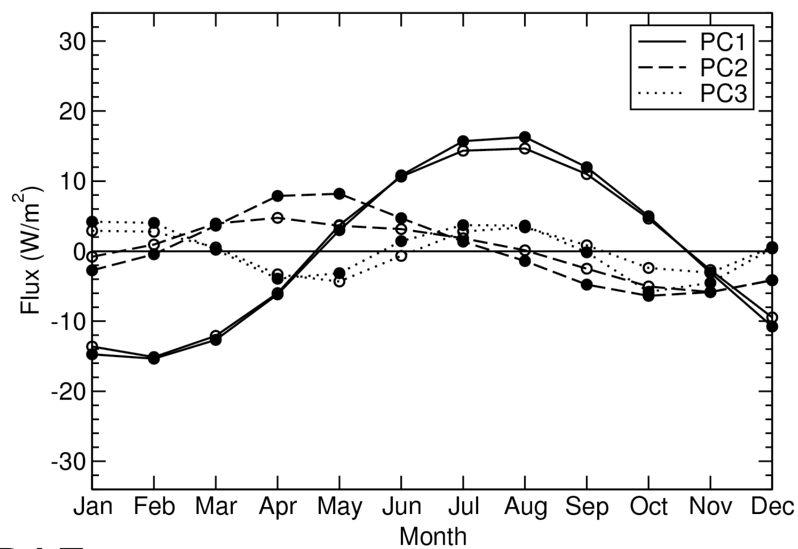


Comparison of the time variations of the EBAF seasonal cycle with those of GEOS-5 from their separate principal component analyses.

OLR Principal Components



Land



Ocean

○ EBAF

● GEOS-5

PC-1 is an annual cycle, lagging the ASR.

For ocean, PC-2 is an out-of-phase annual cycle and PC-3 is the semi-annual cycle. The semi-annual cycles are associated with north-south movements of cloud systems in the tropics and subtropics.

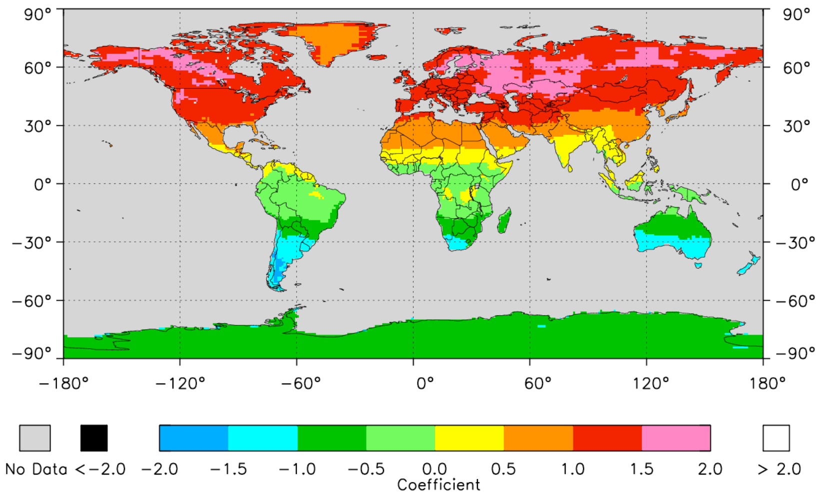
Question:

- The time variations shown by the principal components agree very well.

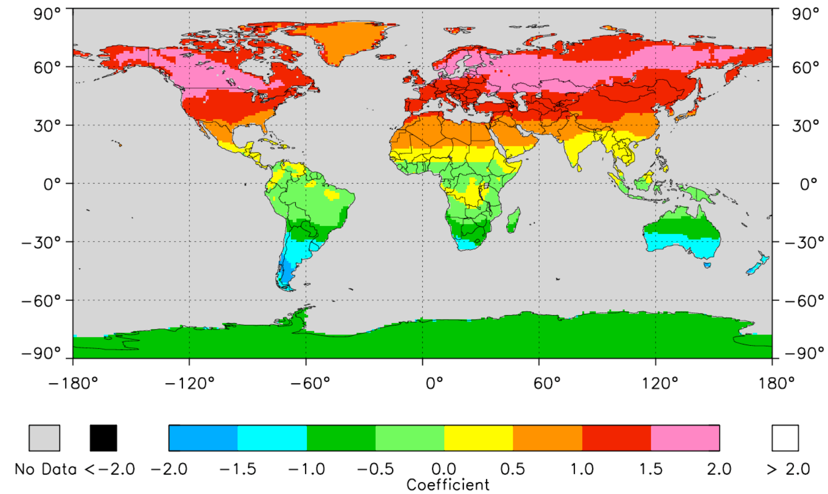
BUT

- How well do the geographic variations shown by the EOFs compare?

Absorbed Solar Radiation EOF-1



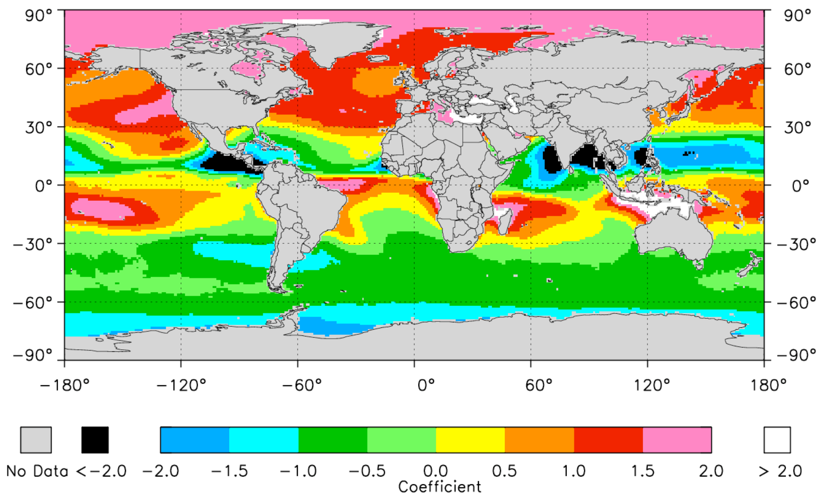
EBAF



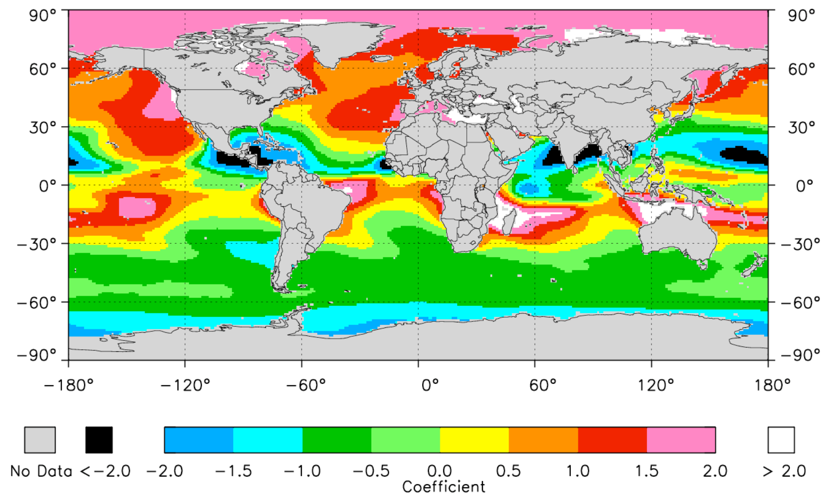
GEOS-5

- Positive EOF-1 values in the NH indicate the annual cycle (represented by PC-1) will peak during NH summer. Likewise, negative values in the SH show that ASR will peak during SH summer.
- Over the tropics EOF-1 is very small because the seasonal cycle is very small.
- Values increase poleward.
- Structure is primarily zonal with longitudinal variations due to clouds.
- Visual agreement between EBAF and GEOS-5 is good.

Outgoing Longwave Radiation EOF-1



EBAF



GEOS-5

- As for ASR, EOF-1 values go from positive to negative as you go from NH to SH.
- Negative/positive bands in the tropics indicate movement of cloud systems and subsidence zones.
- Visual agreement between EBAF and GEOS-5 is good.

Question:

- Visually, both the PCs and EOFs of the seasonal cycles agree well.

BUT

- Since the PCs and EOFs are not exactly the same, we cannot simply subtract them to obtain the seasonal cycle difference between EBAF and GEOS-5.
- How do we quantitatively compare the seasonal cycles?

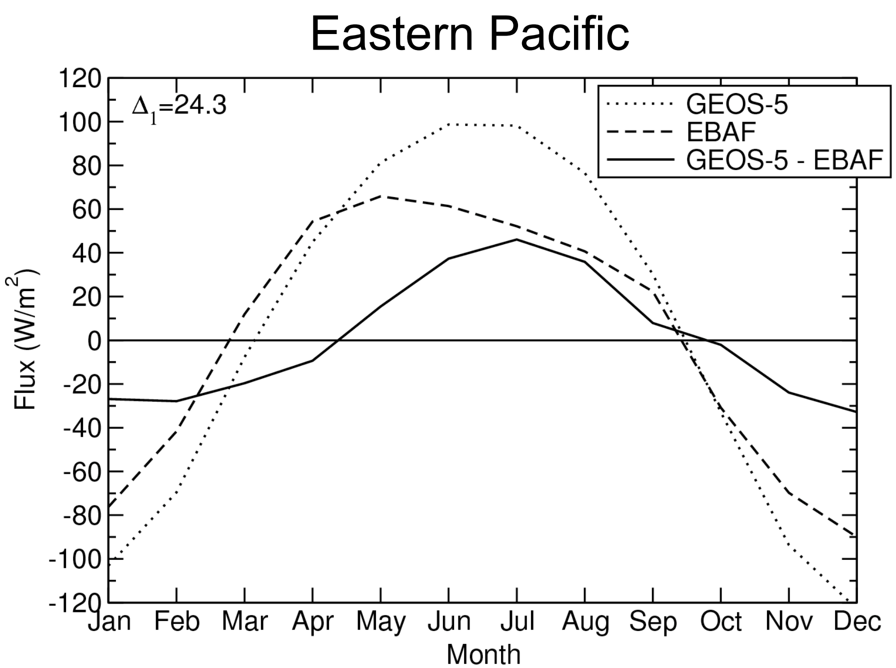
Seasonal Cycle Difference

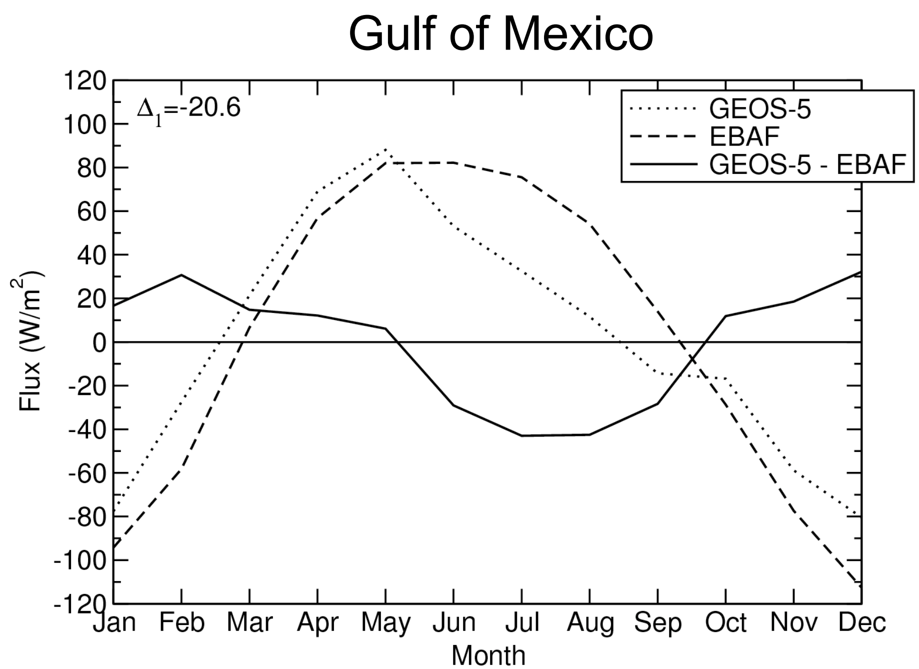
- Project the difference in the seasonal cycles between GEOS-5 and EBAF onto one set of PCs:

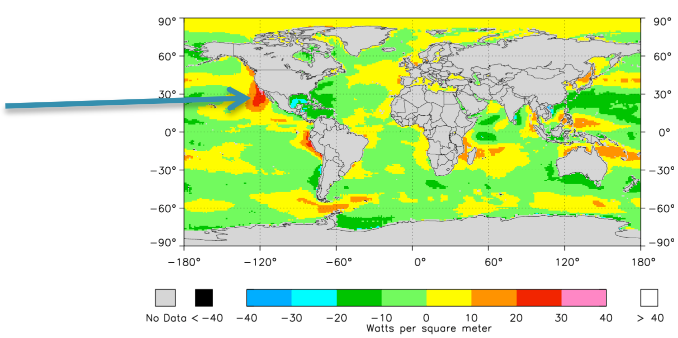
$$[y(x,t) - Y(x,t)]\phi_1(t) = \Delta_1(x)$$

- $\phi_1(t)$ is the normalized EBAF PC.
- To understand what the Δ_1 values actually mean, it is helpful to look at a few specific regions.
- Generally, a positive Δ_1 value shows that the GEOS-5 seasonal cycle is larger than EBAF, and a negative Δ_1 value shows that the GEOS-5 seasonal cycle is smaller than EBAF.

Regional look at differences in seasonal cycles of ASR







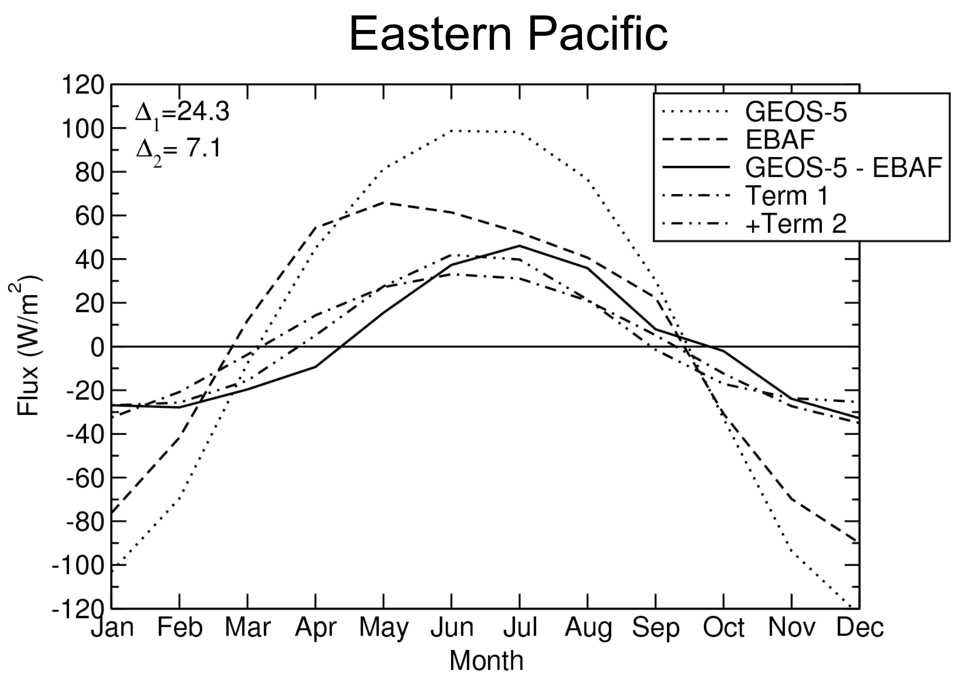
Seasonal Cycle Difference

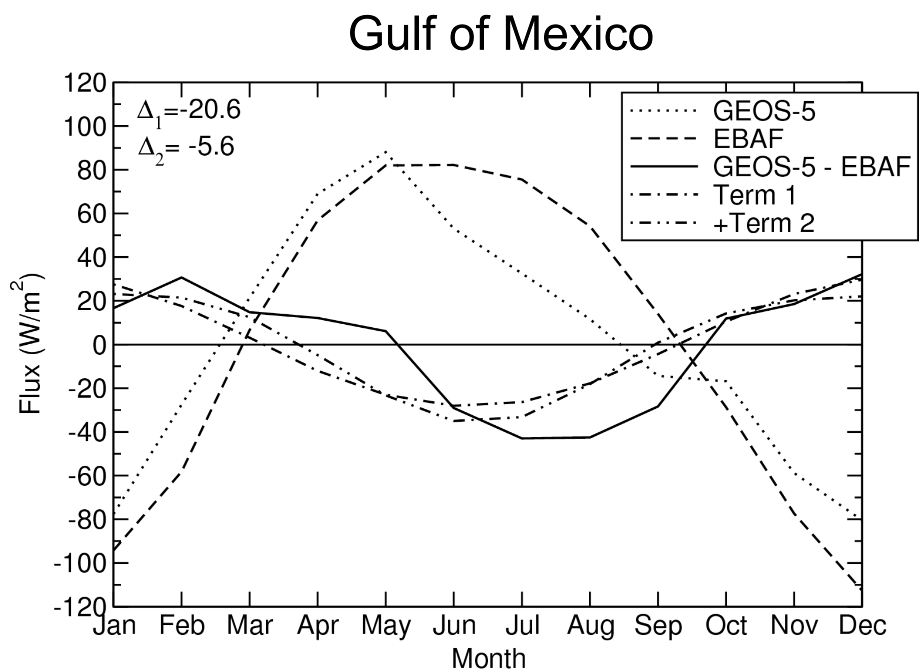
- We can use the $\Delta_n(x)$ values to reconstruct the difference in the seasonal cycles:

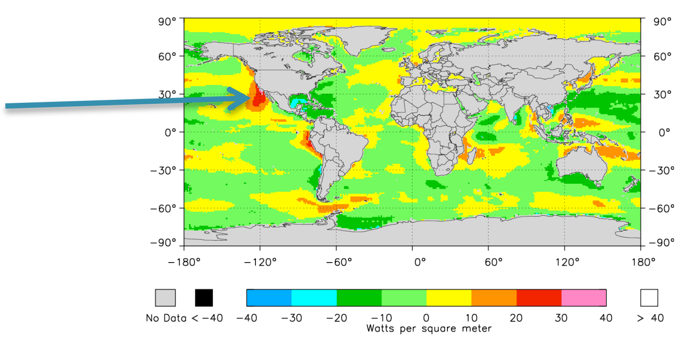
  $$y(x,t) - Y(x,t) = \Sigma_n \Delta_n(x)\phi_n(t) \text{ for n=1-12}$$

- Since the first two PCs of ASR account for nearly all of the variance in the seasonal cycle, we reconstruct the difference with just the first two terms, n=1 and 2.
- Note that in general, for ASR, the first term alone ($\Delta_1\phi_1$) comes close to the actual difference y(x,t) - Y(x,t).

Regional look at differences in seasonal cycles of ASR with reconstruction







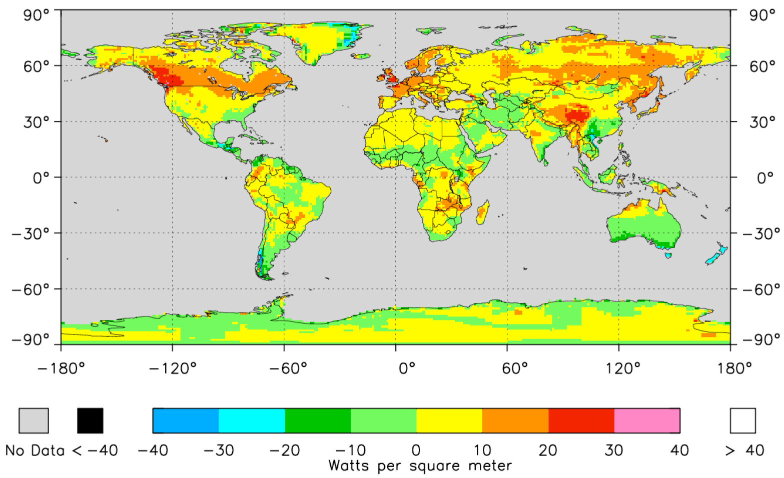
Term 1 and Term 2 are the reconstructions of the differences of the seasonal cycle

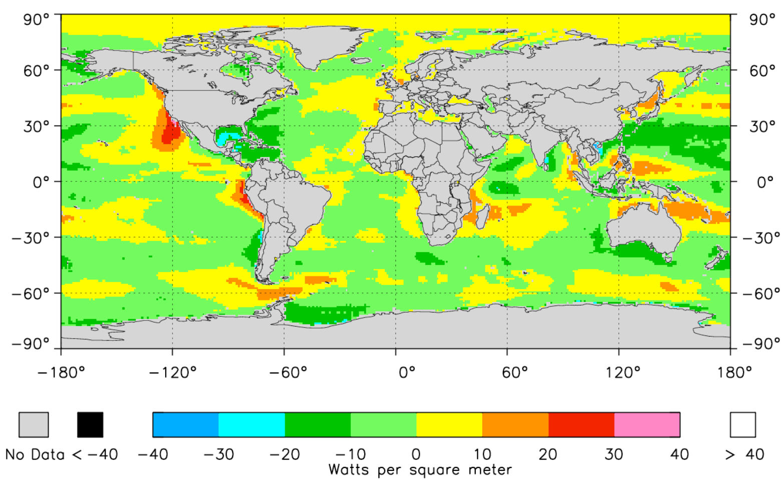
Maps of Seasonal Cycle Differences $\Delta_1(x)$

- $\Delta_1(x)$ can be computed for every region of the globe.
- $\Delta_1(x)$ is a map with units of W m^{-2}. This map will give us a sense of where and by how much the seasonal cycles differ.
- Δ maps are created with higher order PCs as well, but since most of the seasonal cycle is explained by the first PC, we focus on $\Delta_1(x)$.

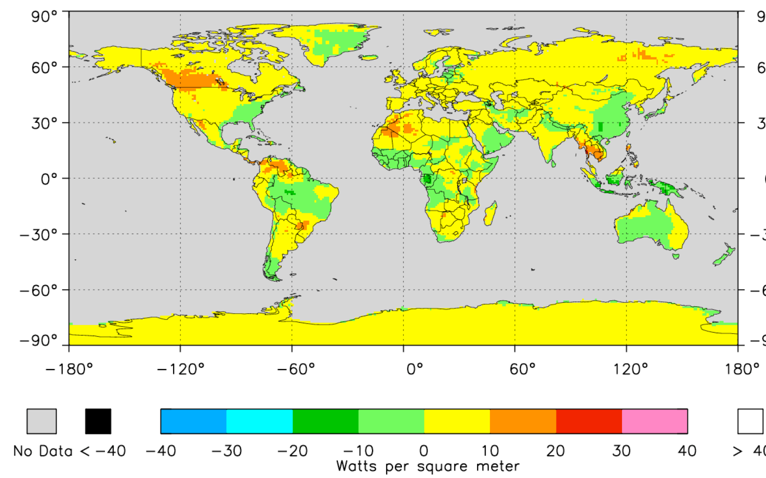
Maps of Seasonal Cycle Differences, $\Delta_1(x)$: GEOS-5 – EBAF projected onto EBAF PC_1

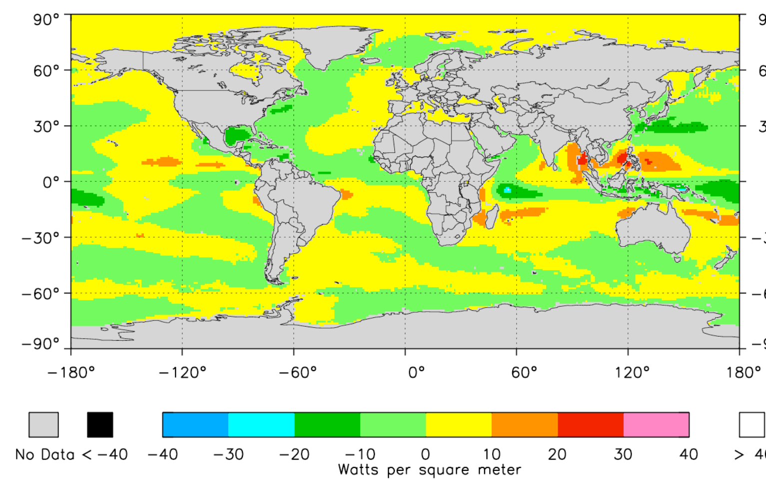
Absorbed Solar Radiation



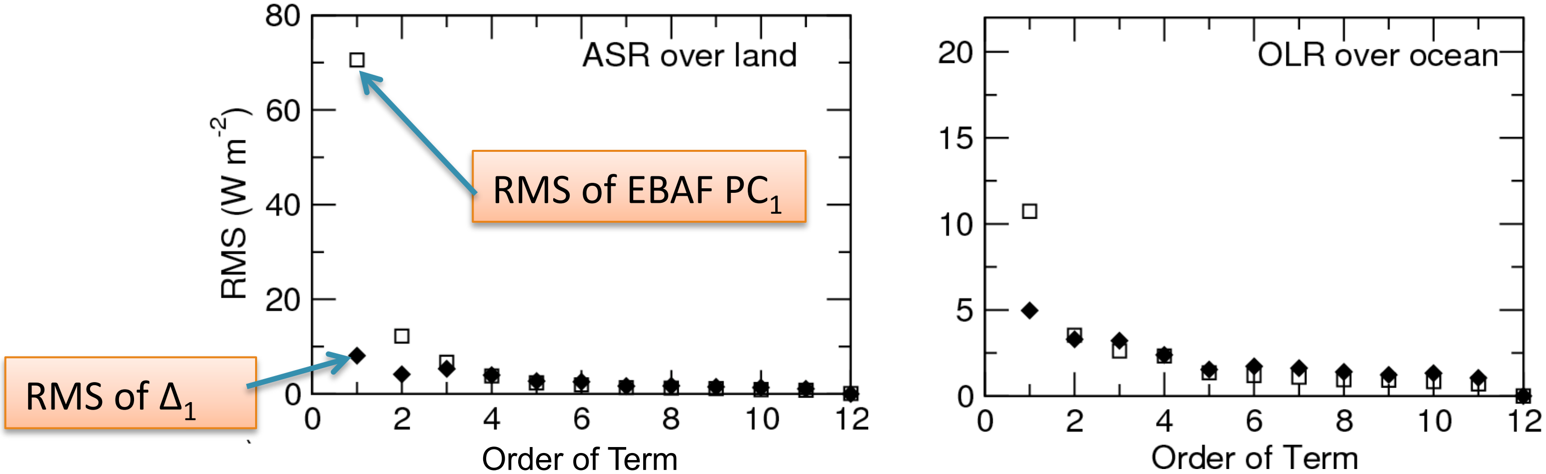


Outgoing Longwave Radiation





Comparison of EBAF RMS with RMS of $\Delta_n(x)$



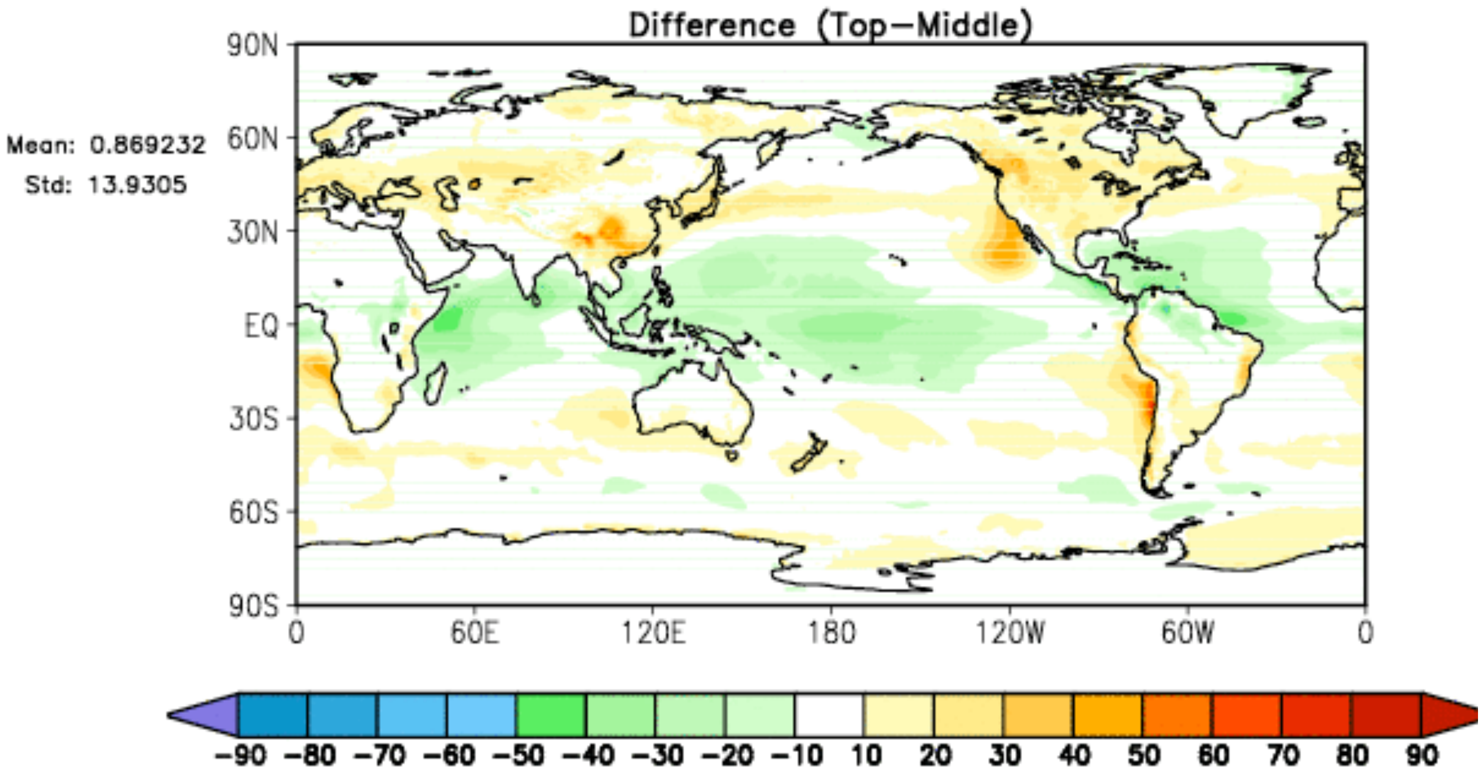
- Each term in the representations of the seasonal cycle (PCs) and the difference in the cycles (Δ_n) has its own RMS.
- For ASR, the EBAF PC$_1$ explains most of the variance, so its RMS (>70 W m^{-2}) is much larger than those of successive terms.
- The RMS of the Δ_1 map is much smaller than the RMS of the EBAF PC$_1$, which says that GEOS-5 is doing a good job of representing the seasonal cycle.
- For OLR over ocean, the seasonal cycle is much smaller than that of ASR.
- But the RMS of the Δ_1 map for OLR is on the same order as that for ASR.

Conclusions

- Principal component analysis of the seasonal cycle of radiation provides a strong validation method for comparing data sets.
- The method gives quantitative measures of agreement/discrepancies.
- Overall, GEOS-5 simulates the absorbed solar radiation and outgoing longwave radiation quite well.
- A few discrepancies are noted.

More conclusions – in Lou's words

- Principal components of GEOS-5 and CERES for ASR compare extremely well
- Not difficult for absorbed solar, since that is mostly driven by solar declination.
- But, the clouds could have a big influence and disrupt the phase.
  - Good News: they don't.
- Next, the PCs for OLR compare extremely well, so the OLR phase is good.
  - That says that the global mean (in some sense) heat storage is good.
- Again, clouds could disrupt, but they don't.
- By comparing in the time domain, the phase is obtained
  - not apparent with snap shots, i.e. monthly maps.
- Harmonic analysis also produces phase info - sine and cosine to get phase and magnitude.
  - For this problem, this info falls out.



Difference (Top−Middle)
Mean: 0.869232
Std: 13.9305
90N
60N
30N
EQ
30S
60S
90S
0
60E
120E
180
120W
60W
0
−90
−80
−70
−60
−50
−40
−30
−20
−10
10
20
30
40
50
60
70
80
90

Principal Component Analysis

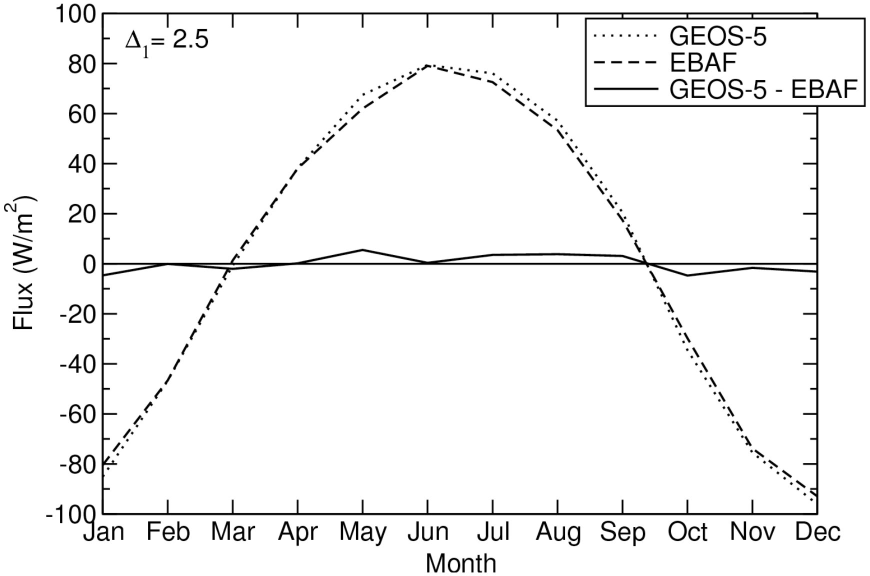
- For each of 39734 grid boxes covering the ocean we have a vector v_x of 12 monthly values. Form the Covariance Matrix $\boldsymbol{M}$ as

$$\boldsymbol{M} = \sum_{\boldsymbol{x}} v_{\boldsymbol{x}} v_{\boldsymbol{x}}^{t}$$

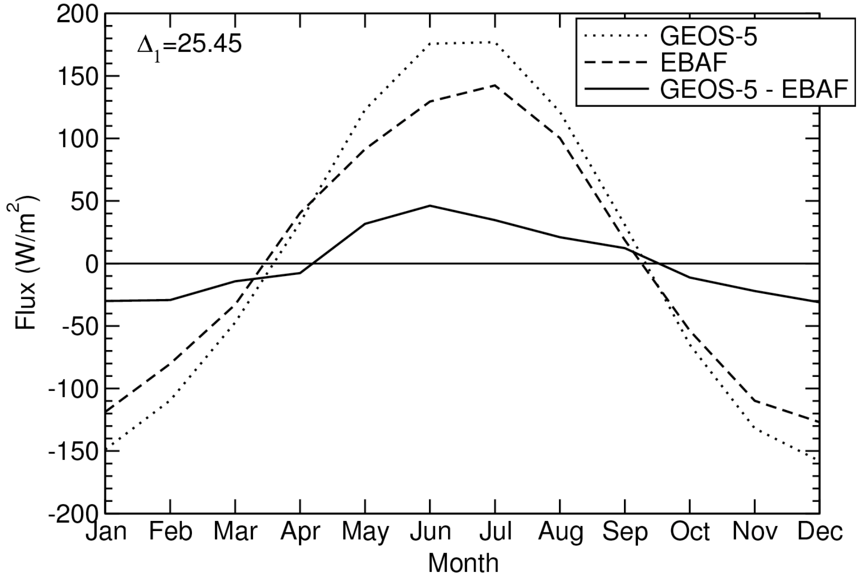
- The eigenvectors of M are the PCs $\Phi_n(t)$.
- The PCs are projected onto the data to produce the Empirical Orthogonal Functions $EOF_n(x)$.

Other regions- ASR

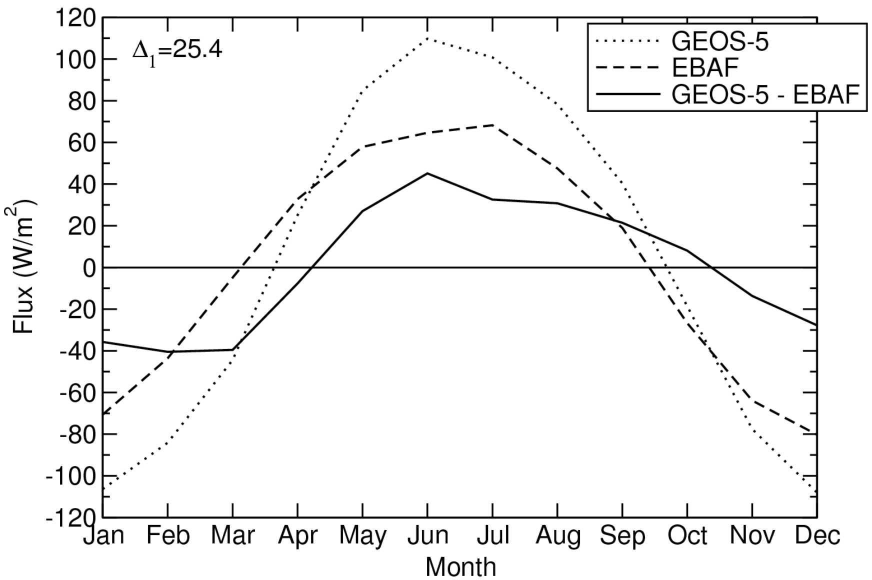
Algeria



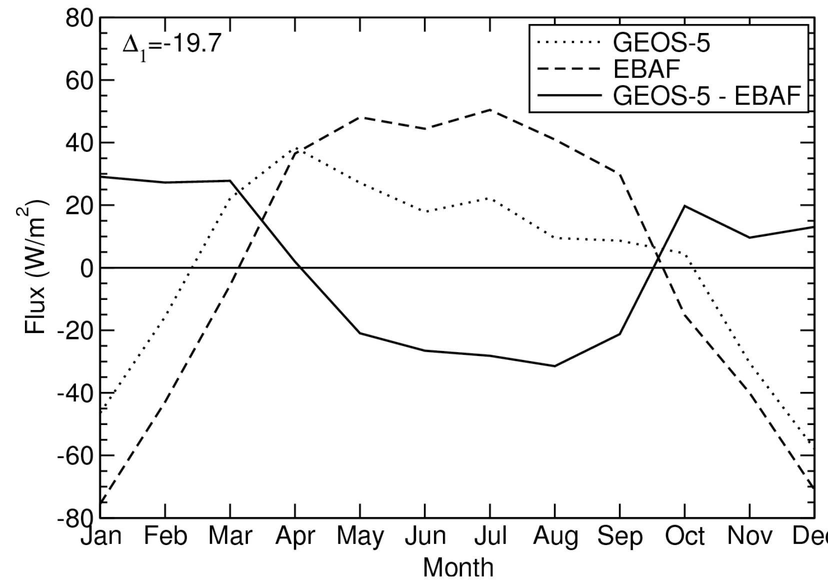
Canadian Rockies



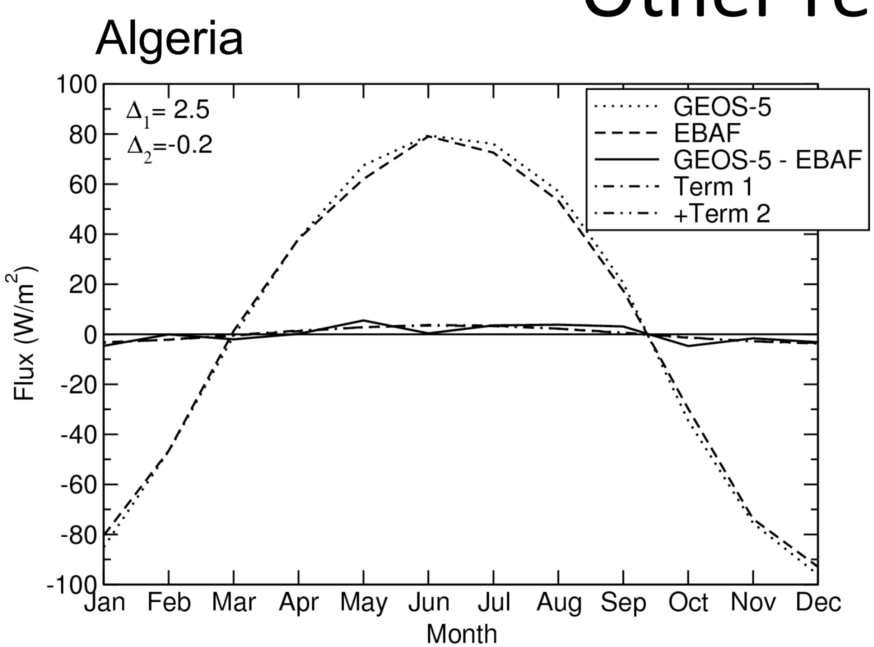
Tibetan Plateau

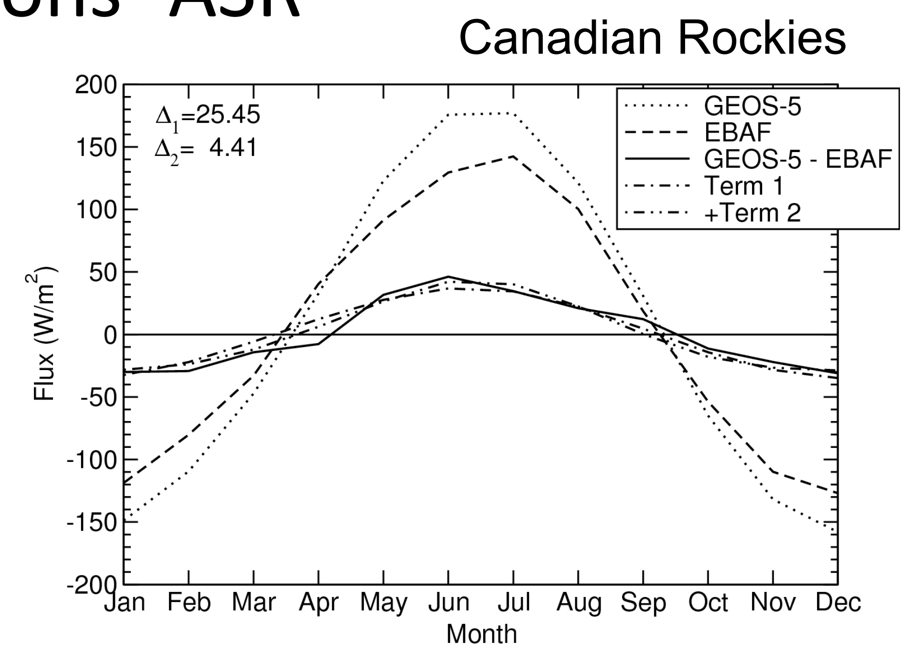


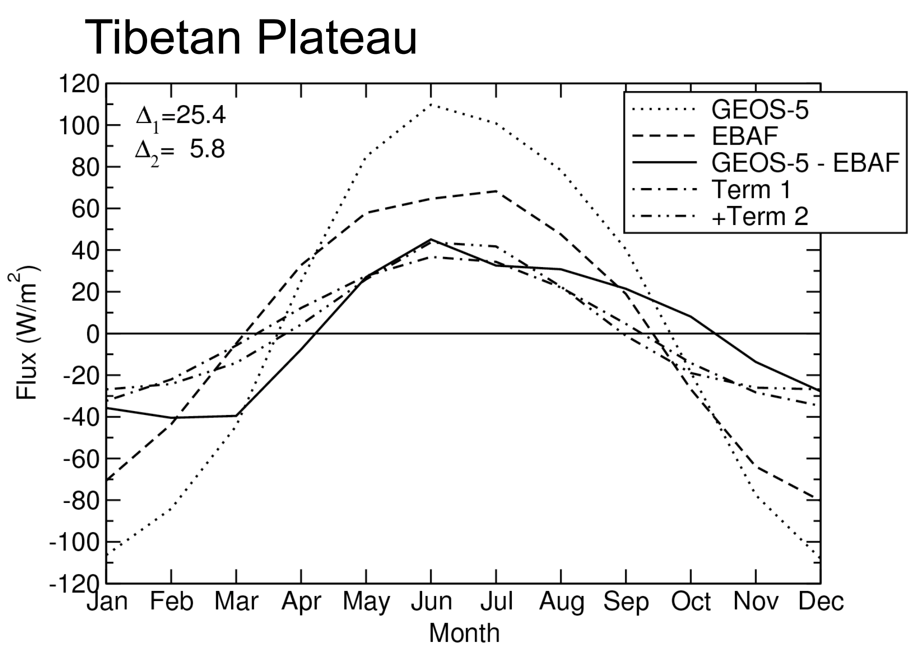
China - Vietnam

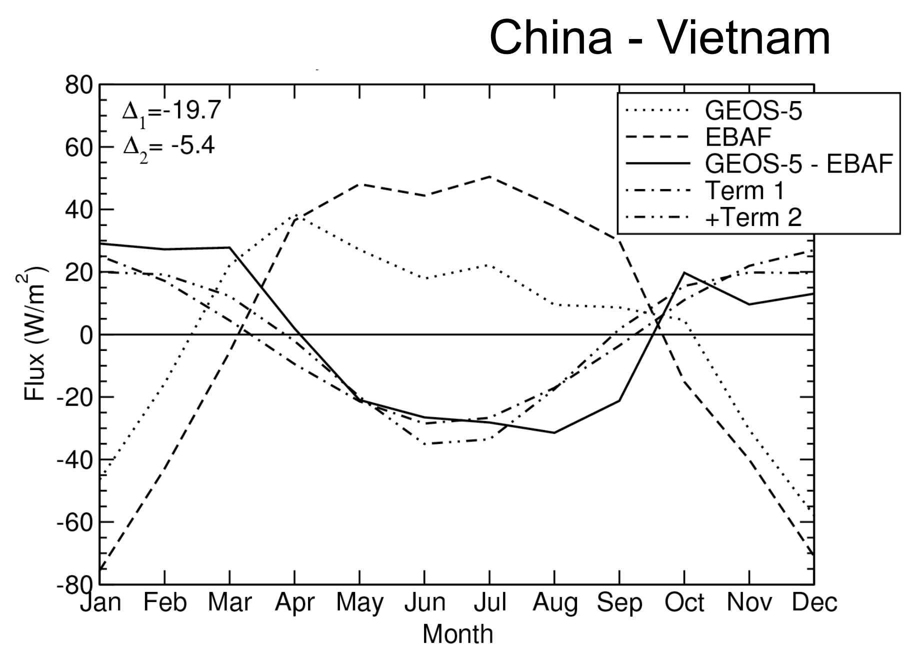


Other regions- ASR









Comparison of EBAF RMS with RMS of $\Delta_n(x)$

LINES